TS 4001: Lecture Summary 5

Powering

Powering

- Resistance is only the means to get to power.
- The real question is:
  – How fast can the ship go?
  – How much power to install for a required speed?

First Relationships

- (Power) = (Force) x (Speed)
- (Force) ~ (Resistance)
- (Resistance) ~ $(\text{Speed})^2$ x (Wetted Surface)
- (Wetted Surface) ~ $(\text{Volume})^{2/3}$ or $(\text{Displacement})^{2/3}$
- Therefore:
  - (Power) = (Coefficient) x $(\text{Speed})^3$ x $(\text{Displacement})^{2/3}$
  - This (Coefficient) is known as the “Admiralty Coefficient”

Initial Powering Estimates

- Parametric data most appropriate for concept designs
  - Scaled power from similar ships

$$SHP_2 = SHP_1 \left(\frac{V_2}{V_1}\right)^3 \left(\frac{\Delta_2}{\Delta_1}\right)^{2/3} \left(\frac{PC_1}{PC_2}\right)$$

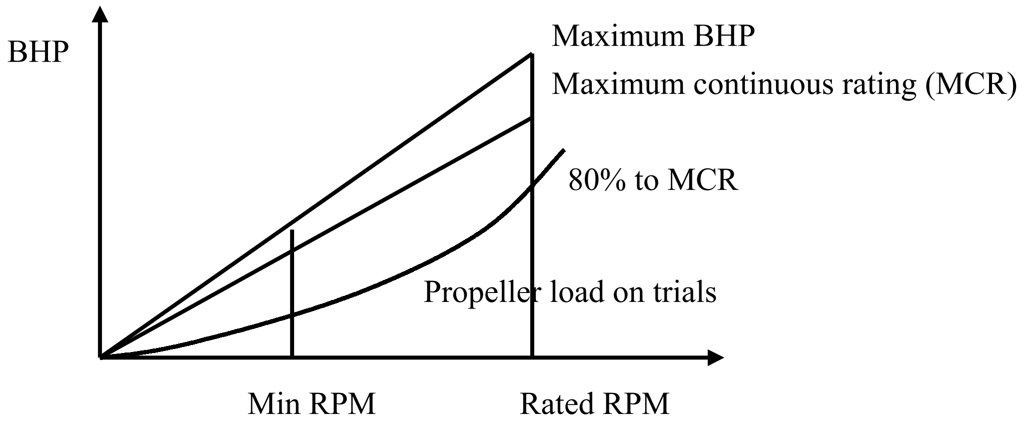
  - Regression analysis of similar ships
- Standard series methods
  - More accurate analysis which requires more detailed information
  - Frictional resistance based on ITTC-57 or other friction line
  - Residuary resistance from Taylor, Series-64, SSPA, or NPL series
  - Many codes exist for these predictions
- Estimated propulsive coefficients
  - Regression analysis for PC, η_o, wake fraction, and thrust deduction
  - Educated guess for transmission, shafting, and η_P

Powering Estimates

- Method of Admiralty Coefficient works well for similar designs.
- Methods such as Silverleaf & Dawson and Holtrop are based on parametric equations and a large regression analysis.
- Estimation of power through systematic series:
  - Estimation of effective power and propeller performance separately.
  - Use the ITTC line for frictional resistance.
  - Estimate or calculate the hull wetted surface.
  - Estimate the residuary resistance through Taylor series, Series 60, etc.
  - Estimate the propeller efficiency through regression analysis or propeller charts.
  - Estimate wake fraction, thrust deduction factor, and relative rotative efficiency from regression formulas.

Powering Margins

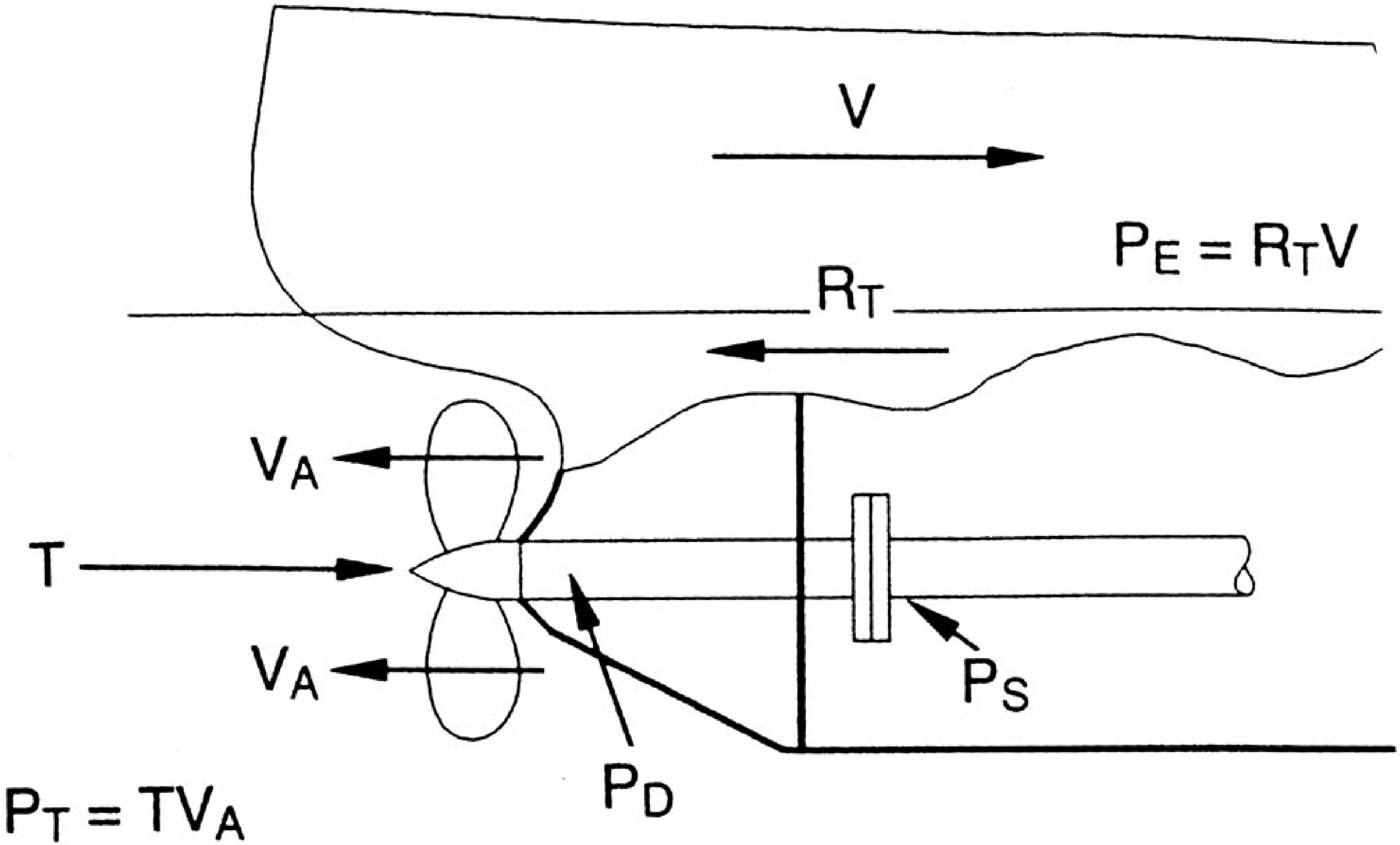
- Design margin:
  - 10% Very early predictions before body plan and appendage configuration
  - 8% Preliminary design predictions made prior to model tests
  - 6% Preliminary and contract design after SHP test with stock propeller with corrections for expected propeller
  - 2% Contract design after SHP test with actual propeller design
- Service margin:
  - To allow for sea conditions, hull and propeller fouling, etc.
  - Typically 10 to 20% below MCR.



Powering Software

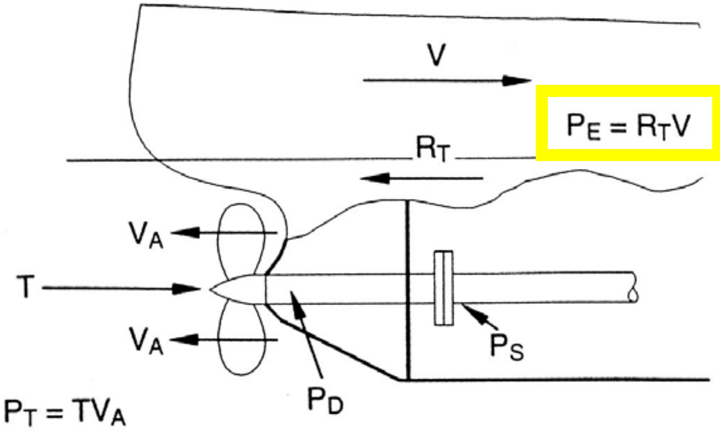
- Use similar designs
- Spreadsheet models
- Warship-21
- PPP
- ASSET
- AUTOHYDRO

Definitions



Effective Power, EHP

- P_E or EHP = power needed to tow ship at a given speed in calm water or power to overcome total resistance force R_T at ship speed V.
- $P_E = R_T V$, where R_T=total resistance and V=speed.
- Can be evaluated straight following resistance calculations.

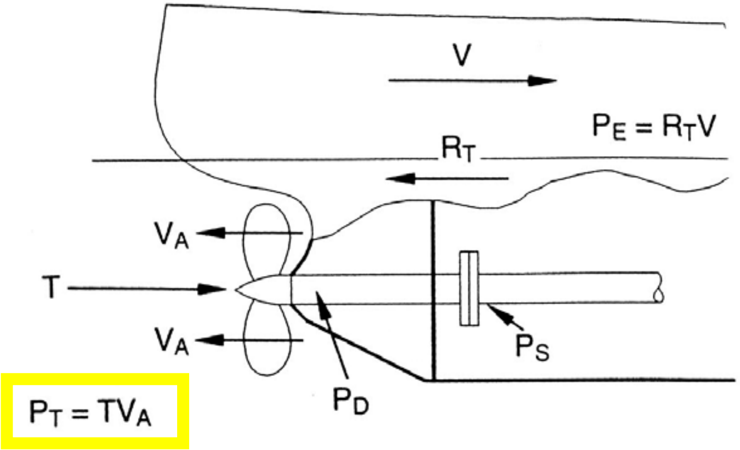


$$\mathrm{EHP} = \frac{R_T V}{550} \text{ where } R_T \text{ [lbs], } V \text{ [ft/sec]}$$

$$\mathrm{EHP} = \frac{R_T V_K}{325.6} \text{ where } R_T \text{ [lbs], } V \text{ [knots]}$$

Thrust Power, THP

- Propeller is producing thrust, T at a speed of advance, V_A.
- Useful power output of the propeller is called the Thrust Power, P_T or THP.



$$P_T = TV_A$$

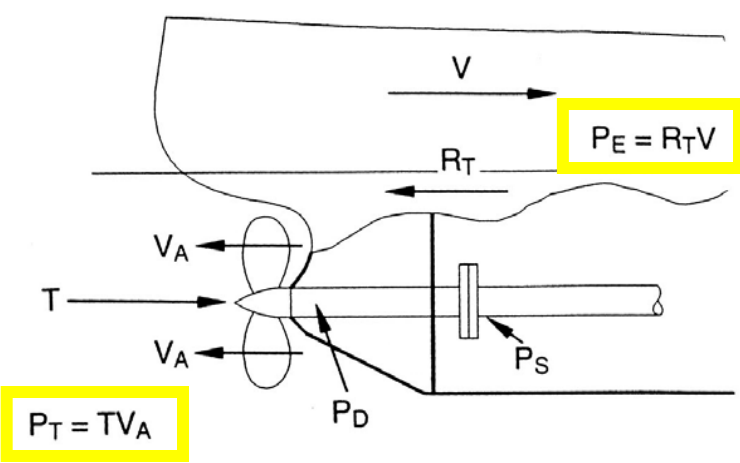
$$T \neq R_T$$

$$V_A \neq V$$

Hull Efficiency

$$\text{Hull efficiency } \eta_H = \frac{P_E}{P_T} = \frac{R_T V}{T V_A}$$

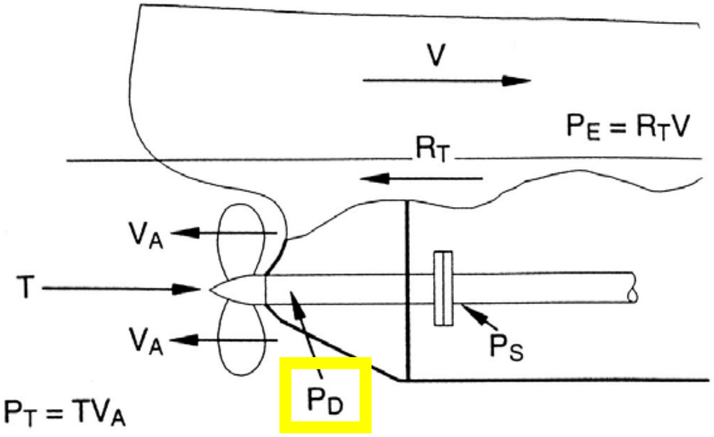
A measure of hull (stern) design to suit propulsor arrangement.



- It does not involve power conversion, so it is not a “true” efficiency.
- It can be greater than one, usual numbers around 1.05.

Delivered Power, DHP

- P_D or DHP = power delivered to the propeller by the prime mover.
- Propeller converts rotating power to thrust power.



$$P_D = 2\pi n Q_D$$

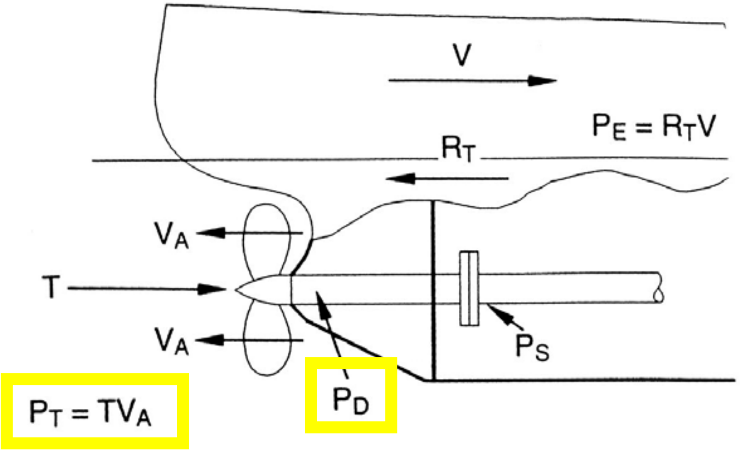
n = Revolutions per second of shaft/propeller.
Q_D = Torque delivered to the propeller.

Propeller Efficiency

- Power conversion between P_D and P_T is where the major loss is.
- Depending on where torque is measured:
  - Efficiency of propeller behind the ship, η_B.
  - Efficiency of propeller in open water, η_0.

$$\eta_B = \frac{P_T}{P_D} = \frac{TV_A}{2\pi nQ_D}$$

$$\eta_0 = \frac{TV_A}{2\pi nQ_0}$$



Q_D = Torque required by the propeller to deliver T at V_A behind the ship.

Q_0 = Torque required by the propeller to deliver T at V_A in open water.

Relative Rotative Efficiency

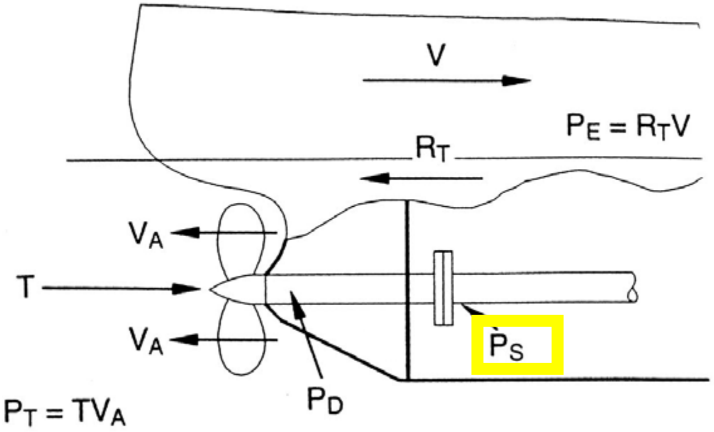
- Defined by the ratio:

$$\eta_R = \frac{\eta_B}{\eta_0} = \frac{Q_0}{Q_D}$$

- It is not a “true” efficiency (not a ratio of powers).
- It can be greater than one.
- Usual values around one.

Shaft Power, SHP

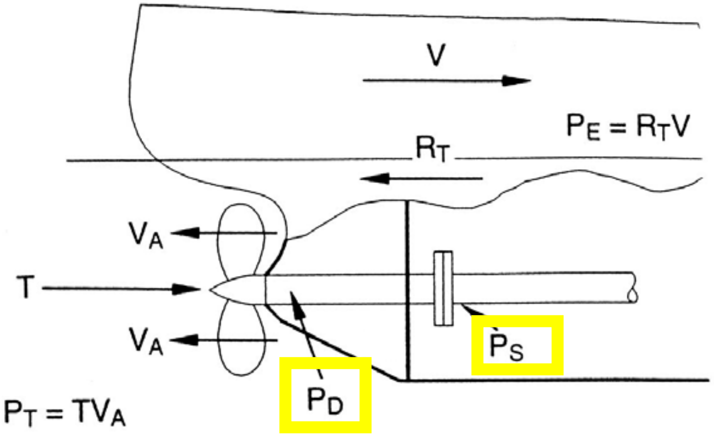
- Power output at the prime mover is higher than delivered power.
- It is usually called shaft power (P_S or SHP) for gas turbines and brake power (P_B or BHP) for diesel engines.



- Occasionally, P_S is the power immediately fore of the stern tube bearing, and P_B is the power right at the prime mover.

Transmission Efficiency

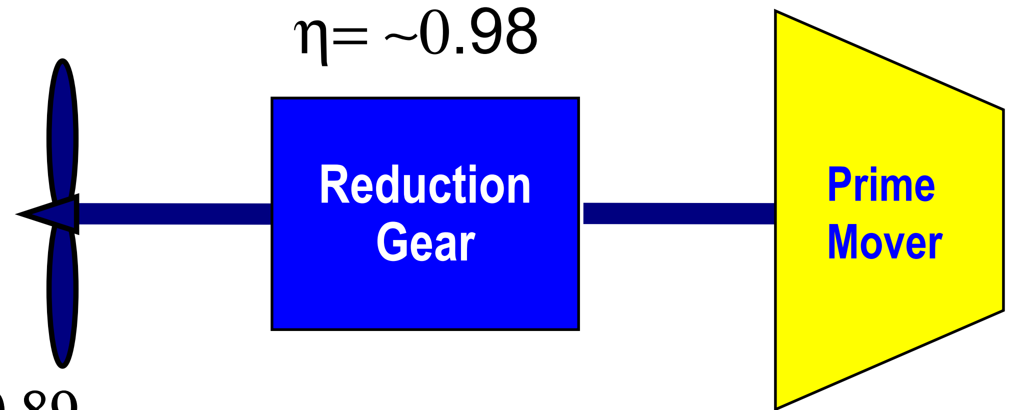
$$\text{Shaft transmission efficiency, } \eta_S = \frac{P_D}{P_S}$$



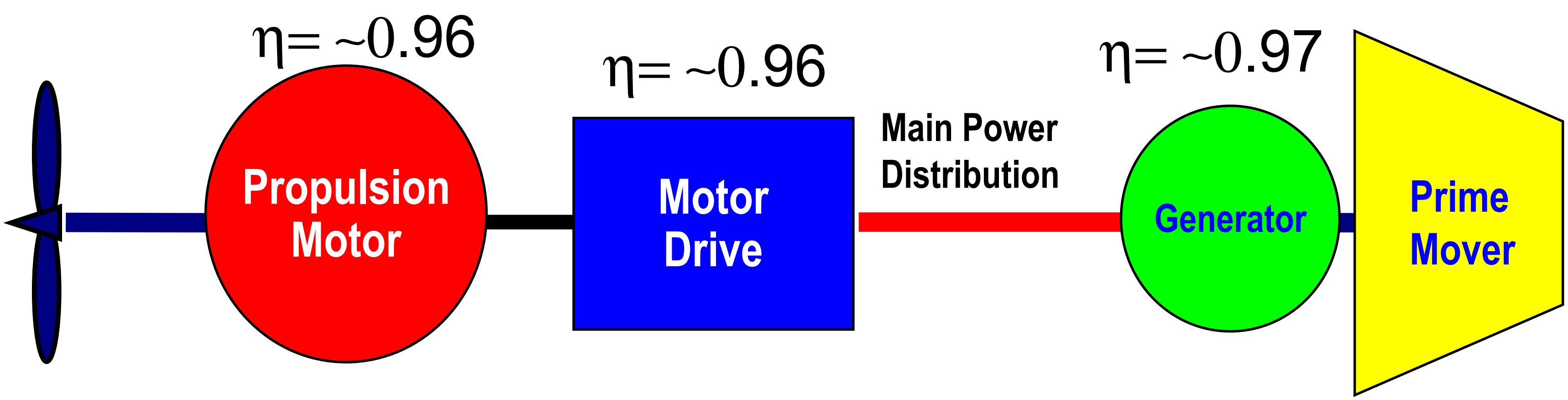
- Occasionally, more than one transmission (or mechanical) efficiencies are defined.
- The overall transmission efficiency will then be the product of the individual components.

Transmissions

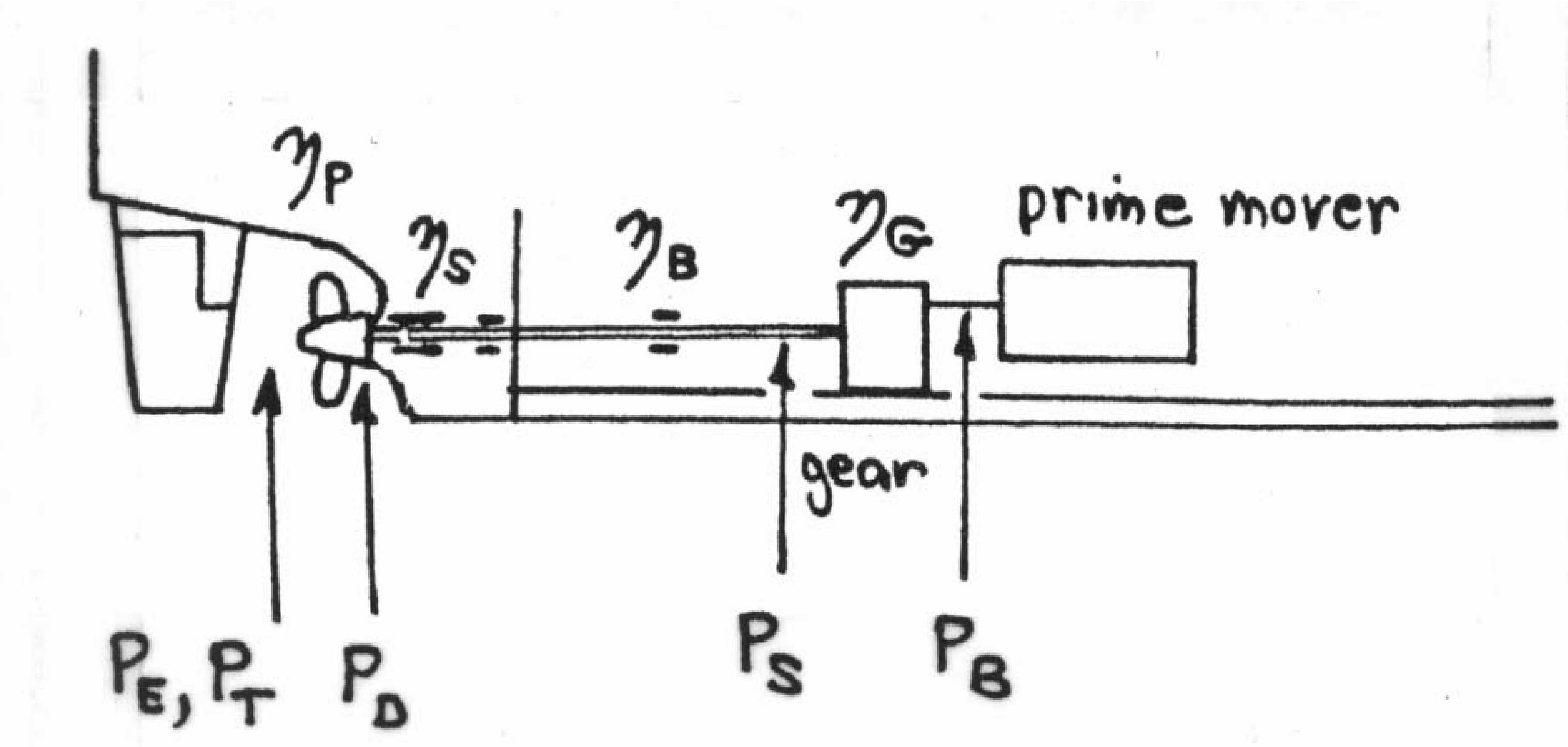
- **Geared Drives**



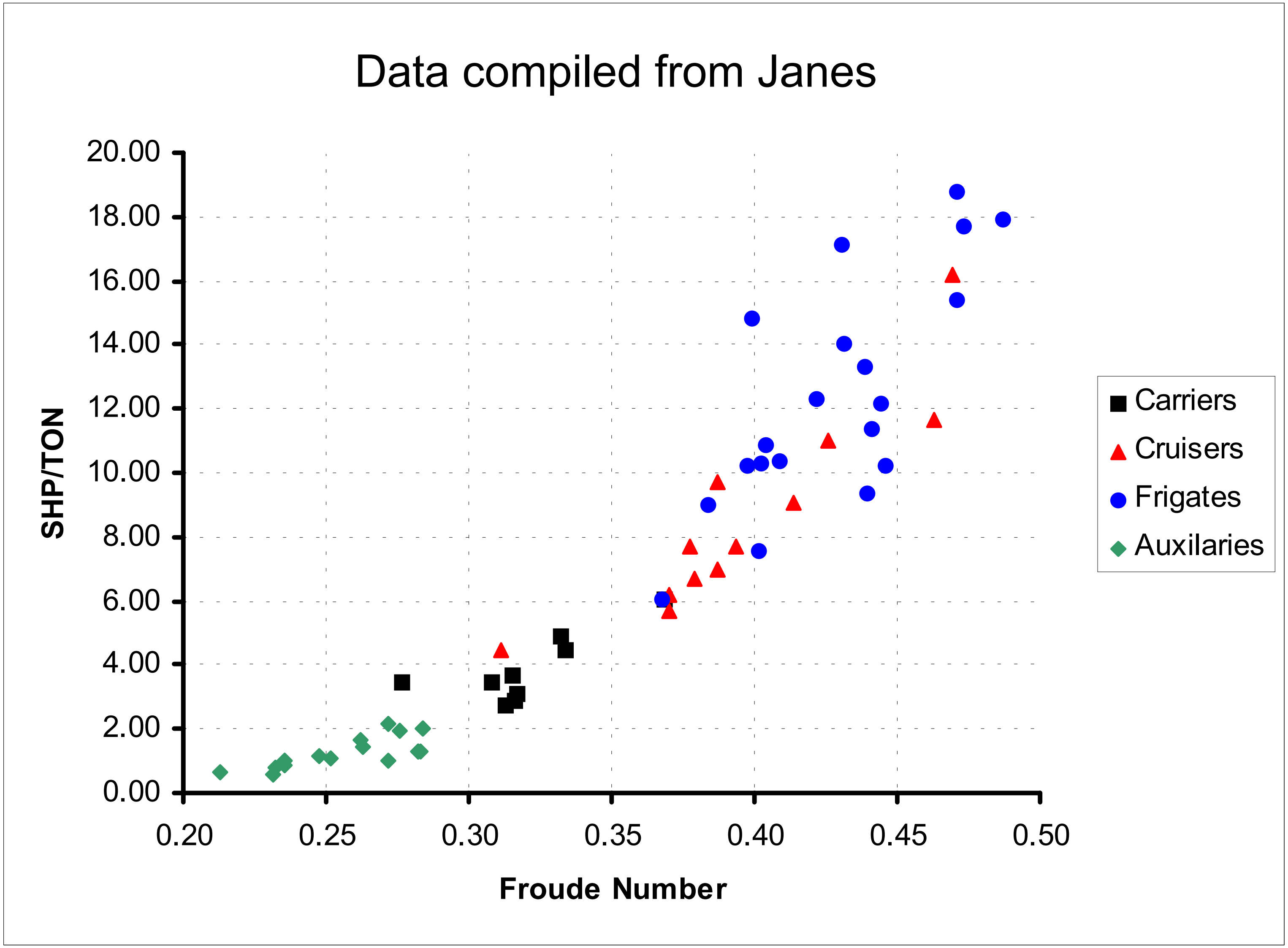
- **Electric Drives** $\eta_{\mathbf{tr}} = \sim 0.89$



Summary



Speed-Power Trends

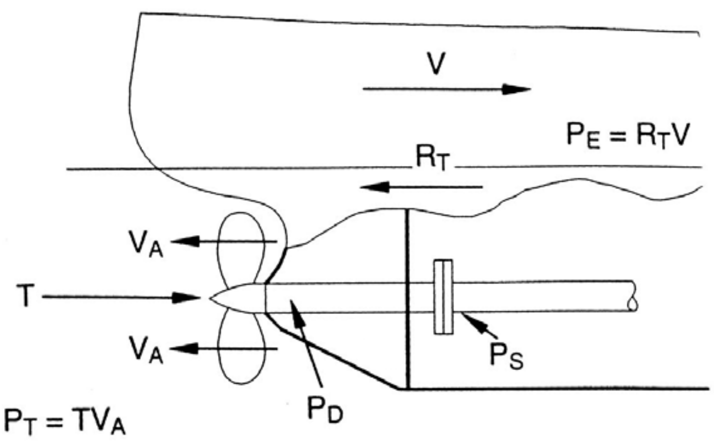


Overall Efficiency

Overall Efficiency, also known as Propulsive Efficiency,

or Propulsive Coefficient (PC) is

$$\eta_P = \frac{P_E}{P_S} = \frac{P_E}{P_T} \times \frac{P_T}{P_D} \times \frac{P_D}{P_S} = \eta_H \eta_B \eta_S = \eta_H \eta_0 \eta_R \eta_S$$



η_H, η_0, η_R depend on hydrodynamics.

η_S depends on mechanical efficiencies.

η_0 is where the major loss is.

The Powering Problem: Maximize η_P

Will do this after we see how propellers work.

Endurance Fuel Estimation

- For Navy designs, use NAVSEA Design Data Sheet (DDS) 200-1
- Standard procedure for calculation based on:
  - Range
  - Cruise speed
  - Required SHP
  - Engine loading
  - Transmission efficiency
  - 24-Hour electric load
  - SFC
  - Margins and allowances
- Second step is to calculate volume required for fuel tankage by multiplying fuel weight in LT by 47.4

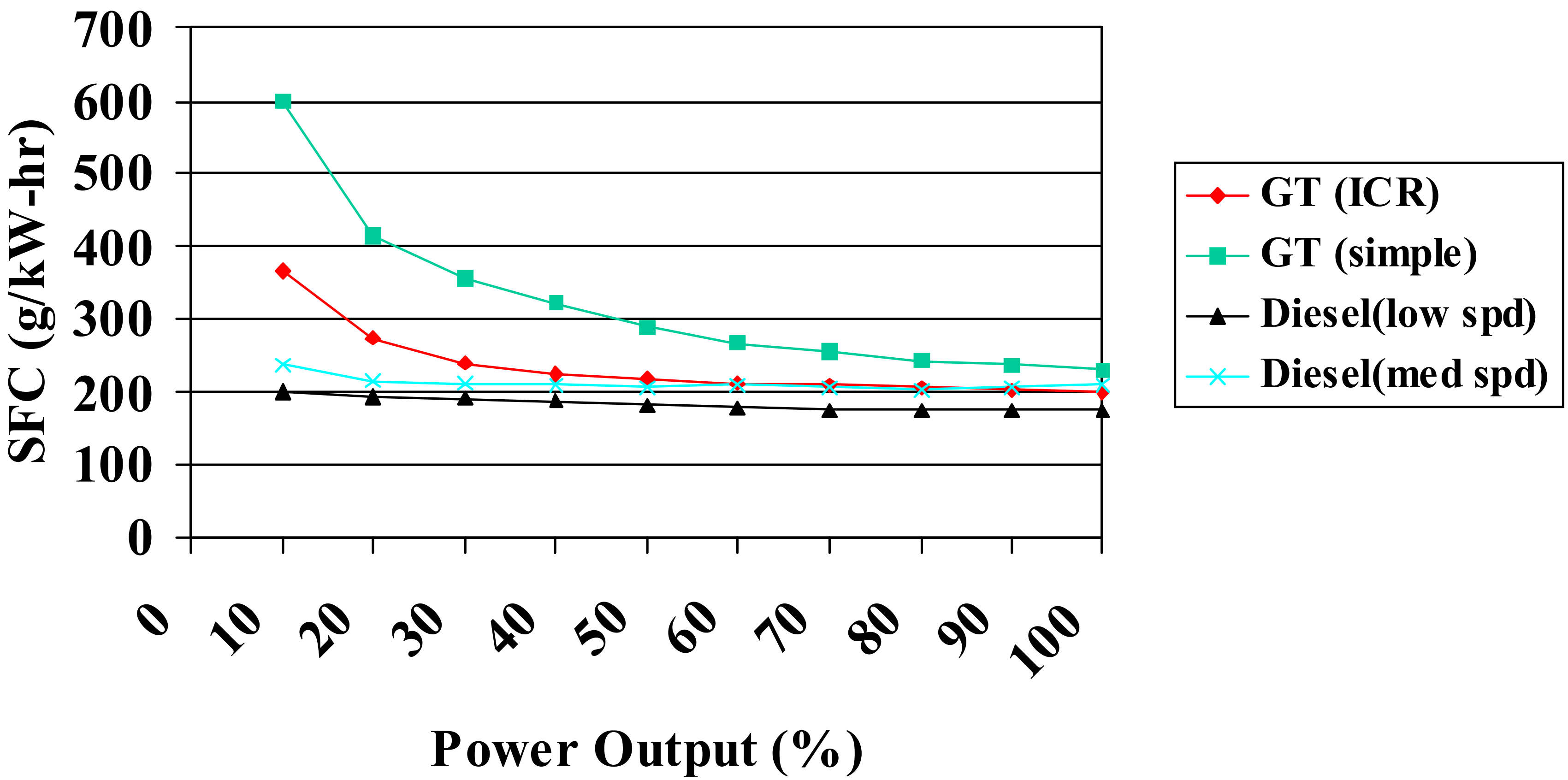
Calculations

NO.	ITEM	UNITS	SOURCE
1	Endurance Required	NM	Given
2	Endurance Speed	KNOTS	Given
3	Full Load Displacement	LTONS	Given
4	Rated Full Power	HP	Given
5	Design Endurance Power @ (2) & (3)	HP	Given
6	Average Endurance Power	HP	(5) * 1.10
7	Average Endurance Power/Rated Full Power		(6) / (4)
8	Average Endurance BHP	HP	(6) / Trans. Eff.
9	24-hour Average Electric Load	kW	Given
10	Propulsion Fuel Rate @ (8)	lb/SHP/hr	Given
11	Propulsion Fuel Consumption	lb/hr	(10) * (8)
12	Generator Fuel Rate @ (9)	lb/hr	Given
13	Generator Fuel Consumption	lb/hr	(12) * (9)
14	Fuel Consumption for Other Services	lb/hr	Given
15	Total All-Purpose Fuel Consumption	lb/hr	(11) + (13) + (14)
16	All-Purpose Fuel Rate	lb/SHP/hr	(15) / (6)
17	Fuel Rate Correction Factor Based on (7)		Given
18	Specified Fuel Rate	lb/SHP/hr	(16) * (17)
19	Average Endurance Fuel Rate	lb/SHP/hr	(18) * 1.05
20	Endurance Fuel	LTONS	(1)*(6)*(19)/(2)/2240
21	Safety Factor		Given
22	**Endurance Fuel Load**	**LTONS**	**(20) / (21)**

Impact of Fuel on Ship System

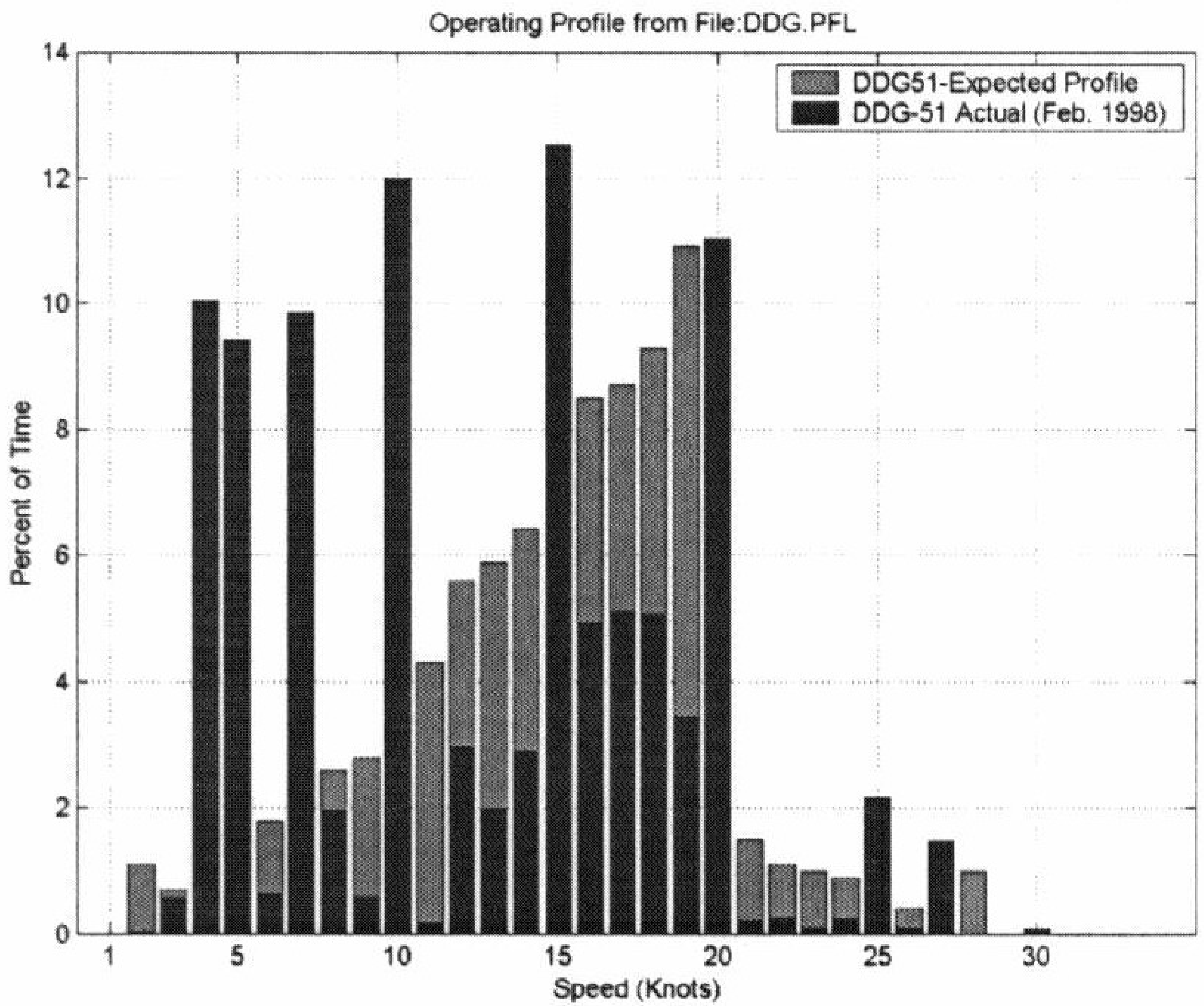
- Range and cruise speed have significant impact on ship size and cost
- Every ton of fuel is one less ton of payload the ship can carry
- For every ton of fuel, ships must now have tankage for one ton of ballast
- If tankage volume exceeds that available in otherwise non-arrangeable areas of the ship, the ship must grow to accommodate the extra fuel
- As required tankage volume increases, the center of gravity of the fuel rises, causing the overall ship KG to rise
- Increased fuel requirement impacts the fuel oil transfer and service systems
- In addition to increased acquisition cost due to extra weight and volume, fuel costs greatly impact annual O&S costs

SFC Comparison

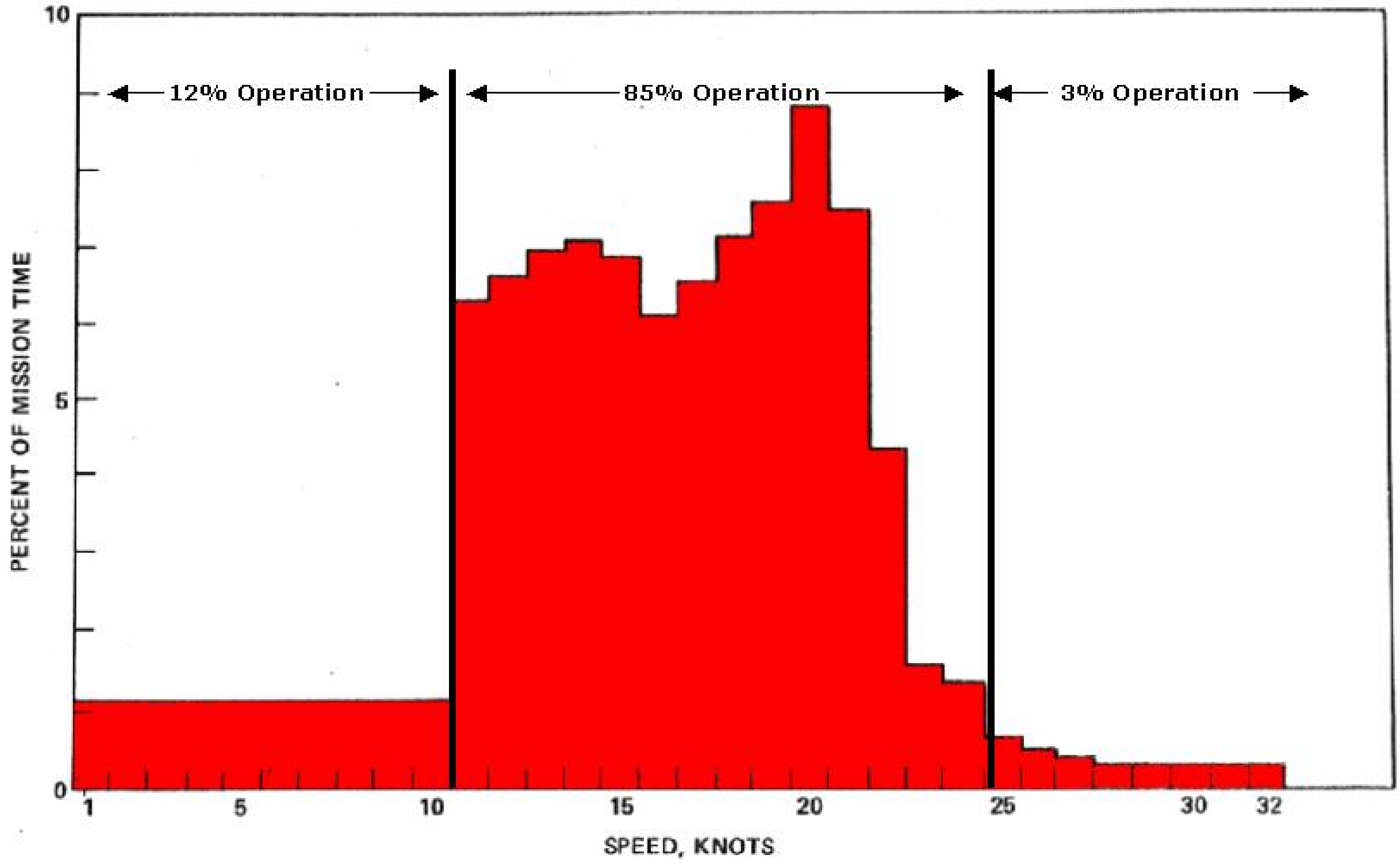


Speed Operational Profile

When comparing power plants take into account the ship's operational profile.



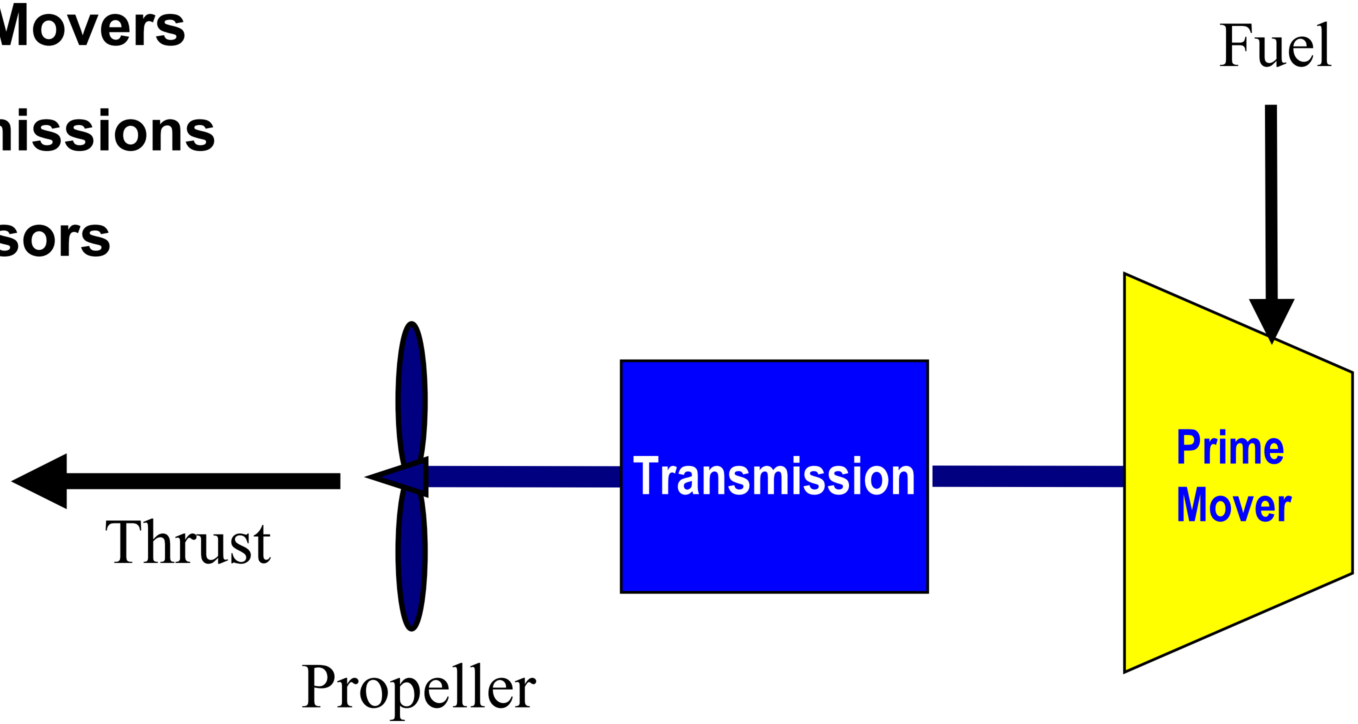
A Typical Profile



Standard Destroyer Mission Profile

Propulsion Plant

- **Subsystems / Components**
  - **Prime Movers**
  - **Transmissions**
  - **Propulsors**



Prime Movers

- Diesels
- Gas Turbines
  - Simple cycle
  - ICR
- Steam
  - Conventional
  - Nuclear
- Fuel Cells
- Combinations

Additional Reading

- 1.4.1 Ship Resistance and Propulsion Notes.
- 1.5.1 The Use of Stern Flap Technology (M. Zoccola).